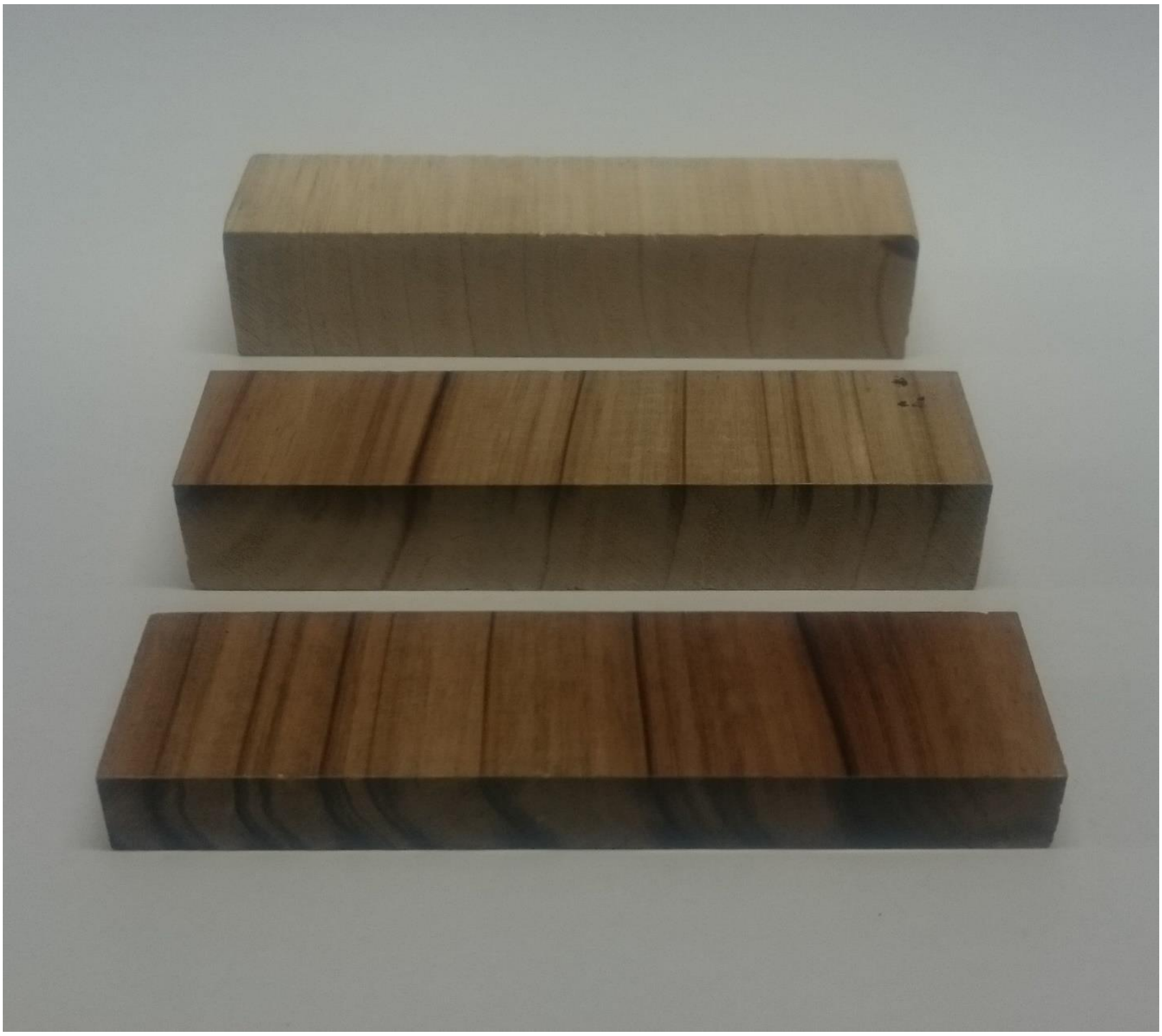
Densification of *E. fastigata* and *E. nitens* for improved surface hardness

Results of Scion's SSIF funded work

Rosie Sargent



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Executive summary

Densification is a method of increasing wood density and hardness using compression and heat to deform and flatten the wood cells. It has been applied experimentally to a number of temperate softwood species worldwide, as well as a few hardwood species. Here the technique is applied to two New Zealand grown eucalypt species (*Eucalyptus fastigata* and *E. nitens*).

Two densification techniques were used, one to compress the entire thickness of the board (bulk densification) and one to just deform and compress one surface (surface densification). Surface densification is intended to give a hard surface, similar to that of bulk densification, but without increasing the overall board density, and without reducing the board thickness as much as the bulk densification.

The *E. nitens* boards were able to be compressed to a greater extent than the *E. fastigata* boards without being damaged (*E. fastigata* was only able to compressed by 20% of its thickness for bulk densification, compared to 50% for *E. nitens*). All densified boards had significant increases in density and surface hardness, with the surface densified boards not having a significantly different hardness to the bulk densified boards.

When soaked in water, the surface densified boards recovered more than 80% of the thickness lost during densification, whereas the bulk densified boards only recovered 40-50% of their original thickness, with the *E. nitens* boards swelling significantly less than the *E. fastigata* boards.

Overall, the *E. nitens* boards densified more successfully, with increased levels of densification possible, and reduced swelling when soaked in water compared to the *E. fastigata* boards.

For both species the surface densifications had the desired effect of increasing the surface hardness without increasing the overall board density, but further work is required to prevent the boards from swelling back to their original dimensions when soaked in water.

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Introduction

Wood densification is a process where wood is heated and compressed to permanently deform and flatten the wood cells. This increases the wood density and consequently improves properties such as hardness. Wood densification has been widely investigated to improve the hardness of many wood species, predominantly European softwoods (Navi & Sandberg, 2012). Non-durable eucalypts grown in New Zealand tend not to be as hard as hardwood species traditionally used for interior products such as flooring (e.g. European Oak). This project aims to increase the hardness of *Eucalyptus fastigata* H.Deane & Maiden and *E. nitens* (H. Deane & Maiden) Maiden through densification, and to retain the densified wood shape over time.

A large amount of densification research to date has been on flat-sawn timber, and anecdotally flat sawn timber is better for this application (A. Kutnar, *pers comm* 2019), however most eucalypts are preferentially quarter sawn, to reduce cupping during drying, and to reduce internal checking. Here both flat and quarter sawn boards have been densified to see if densification of quarter sawn eucalypts is feasible.

There are two methods of densification, bulk densification and surface densification. In bulk densification the wood is heated on both faces and compressed through the entire thickness, leading to a dramatically reduced wood thickness, and increased density throughout the entire board thickness. Surface densification only heats one face of the wood, and compresses the wood to a lesser extent, which only increases the density in a narrow band on one face. This does not reduce the board thickness to the same extent, and doesn't increase the overall board density as much as bulk densification.

Materials and methods

Densification

Eucalyptus fastigata boards were sourced from a previous sawing study (Jones, et al., 2010). The trees were 25 years old and boards were cut from either the butt log or 1st log of each tree. The boards were cut from 10 different trees. *Eucalyptus nitens* boards were also left over from a sawing study of 18 year old trees grown in the southern South Island of New Zealand (Sargent & Gaunt, 2018). These boards were all cut from the 1st log, and were also cut from 10 different trees. For each species, equal numbers of flat- and quarter-sawn boards were cut to 500mm long, and were planed to 20mm thick. The majority of boards were 100mm wide, but some *E. nitens* boards were 90-95mm wide. Each 500mm long board was cut into two matched 250mm long boards. The 250mm long boards were sent to InnoRenew in Slovenia where the testing was performed, and were then assigned to the following treatments:

- Bulk densification
- Surface densification
- Undensified control

Each combination of species and densification treatment had 20 boards (half flat-sawn, half quarter-sawn).

It was intended to compress the bulk densified boards to 10mm thick, and the surface densified boards to 16mm thick, however the quarter-sawn *E. fastigata* boards developed numerous cracks when compressed below 16mm, so the *E. fastigata* boards were compressed to 16mm thick for bulk densification, and 17mm thick for the surface densification.

Property testing

For hardness testing, 50mm long blocks were cut across the entire width of each board, starting around 5mm from the board end. A modified Brinell hardness test was used where a steel ball 11.28mm in diameter was indented 4mm into the surface of the sample and the applied load recorded. Each sample tested was placed on a second board of the same material to mimic the behaviour of a thicker board. Some quarter-sawn bulk densified boards split before the hardness testing was complete. For these boards the applied load and indentation depth at the time of the break were recorded. This test is the standard hardness test used at InnoRenew where the densification work was carried out, and while it is similar to the Janka test normally performed at Scion, the results cannot be directly compared.

Brinell hardness is calculated according to Equation 1.

$$BHN = \frac{2F}{\pi D \left(D - \sqrt{D^2 - d^2}\right)} \tag{1}$$

Where:
F is the applied force (kN)
D is the diameter of the ball (mm)
d is the diameter of the indentation (mm)

Set recovery is the extent to which the densified sample returns to its original dimensions when soaked in water. From each board, two 20x20mm blocks were cut side by side, each at least 5mm from the board edges and 60mm from the board end. For the water soaking test, the blocks had their thickness measured in three places, then were oven dried overnight at 103°C and their thickness measured again. The blocks were then submerged in water at 20°C for 24h, then oven dried at 103°C for 24h and their thickness measured again. The water soaking and oven drying was repeated for a further four cycles.

Set recovery after water soaking is calculated as follows:

$$SR_{WS} = \left(\frac{t_{wOD} - t_{OD}}{t_o - t_{OD}}\right) \times 100 \tag{2}$$

Where:
t_o is the initial uncompressed thickness
t_{OD} is the oven dried thickness following densification
t_{wOD} is the oven dried thickness following water soaking

The nominal density of the wood was calculated from the weight and dimensions of the boards after equilibrating at 20°C, 60% RH for four weeks.

Results and discussion

The set recovery, final density and Brinell hardness for each treatment are shown in Table 1. Within each species and treatment grouping there was no significant difference in performance between the flat-sawn and quarter-sawn boards, so here they have been analysed together. For both species the density increased significantly with increasing levels of densification. The density increases for *E. nitens* were larger, which is not surprising given these samples were compressed to a greater extent. Levels of surface hardness also increased following densification. For both species the surface- and bulk-densified boards were significantly harder than the undensified controls, but were not significantly different to each other. The intention of the surface densification is to increase the surface hardness without a large increase in density, so this is a positive result. For the set recovery, the surface densified boards increased in thickness, regaining over 80% of the thickness reduction caused by densification. In comparison the bulk densified boards regained 50% or less of their thickness when soaked in water. The bulk densified *E. nitens* had a significantly lower set recovery than the *E. fastigata*, suggesting that it would retain its dimensions better over time.

Table 1: Properties following densification.

Species	Densification level	Set Recovery (%)	Density (kg/m^3)	Hardness (kN/mm^2)
E. fastigata	Control	-	620^{a}	23.7^{c}
E. fastigata	Surface	81.3^{a}	707^{b}	34.3^{a}
E. fastigata	Bulk	54.1^{b}	760^{c}	32.8^{ab}
E. nitens	Control	-	453^{d}	15.4^{d}
E. nitens	Surface	86.8^{a}	554^{e}	26.8^{bc}
E. nitens	Bulk	39.7^{c}	837^{f}	33.2^{ab}

Photographs of the densified boards are shown in Figures 1 and 2. The different thickness of the densified boards can easily be seen.

Figure 1: *E. fastigata* boards following densification. From left to right: undensified controls; surface densification; bulk densification.

Figure 2: *E. nitens* boards following densification. From left to right: undensified controls; surface densification; bulk densification.

Recommendations and conclusions

Both *E. nitens* and *E. fastigata* showed an increase in density and surface hardness with densification. For each species, the surface and bulk densifications did not have significantly different levels of surface hardness, but the bulk densified boards were more likely to retain their compressed dimensions when soaked in water. The *E. nitens* boards were able to be densified to a greater extent than the *E. fastigata* boards without damaging the wood, so the *E. nitens* boards had greater increases in density, and the hardness increased to similar levels to the densified *E. fastigata*. When soaked in water the bulk densified *E. nitens* boards changed thickness significantly less than the bulk densified *E. fastigata*. Overall, the *E. nitens* was more amenable to densification that the *E. fastigata*. While the surface densification achieved the aims of increased surface hardness without too much increase in density, or reduction in board thickness, further work is required to reduce the level of swelling when the samples are soaked in water.

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